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A soft and conductive PDMS-PEG block copolymer as a compliant electrode for dielectric elastomers

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Publication date:
2015

Document Version
Peer reviewed version

A soft and conductive PDMS-PEG block copolymer as a compliant electrode for dielectric elastomers

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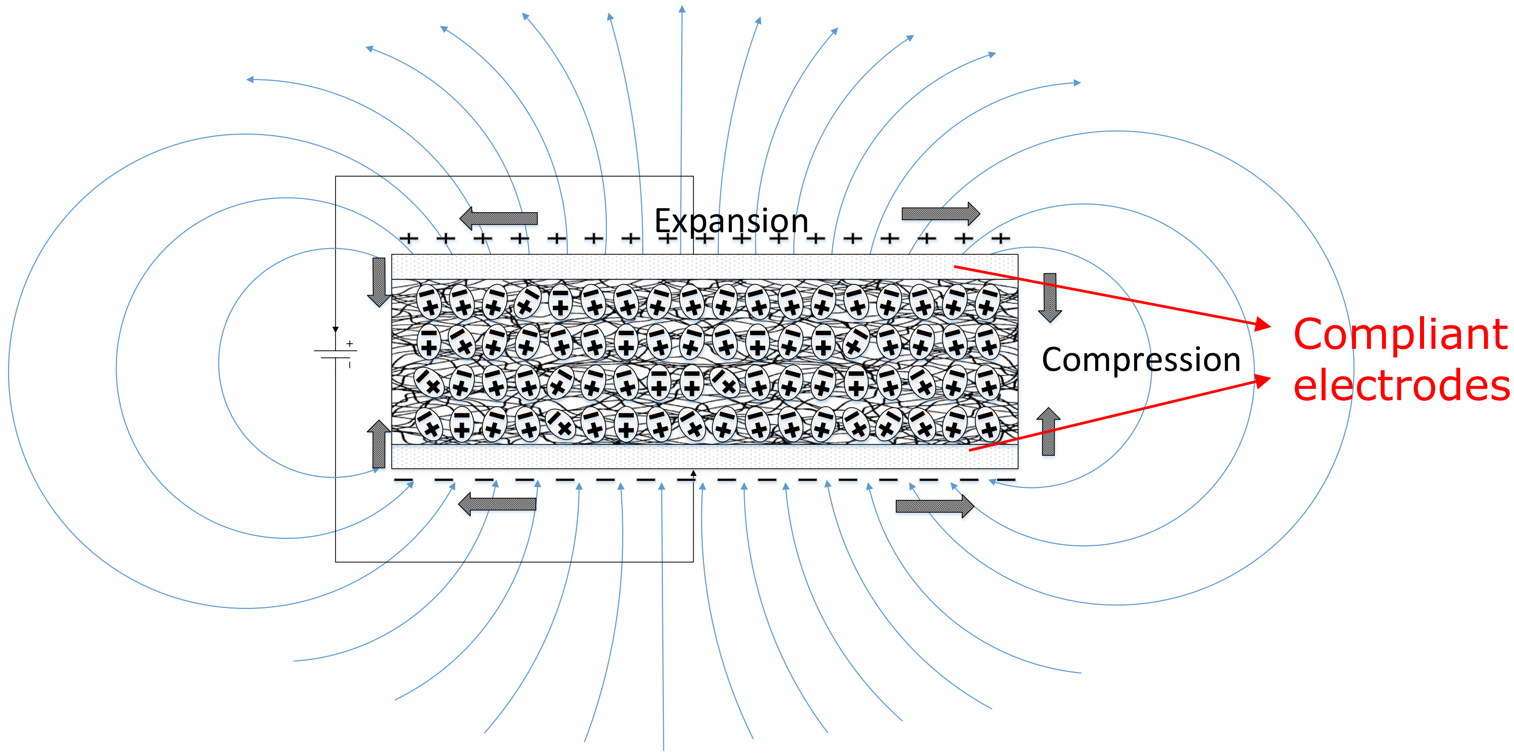
Annual Polymer Day 2015

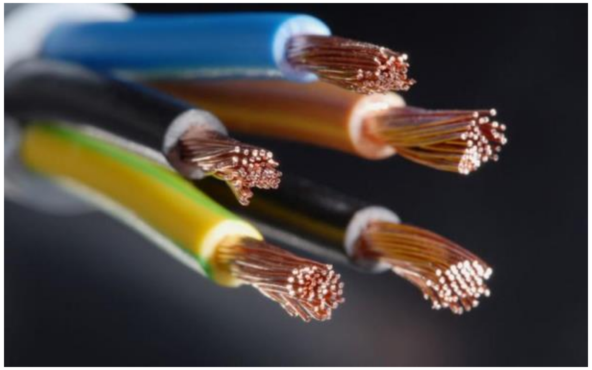
Motivation

Principle of dielectric elastomer (DE) as an actuator:

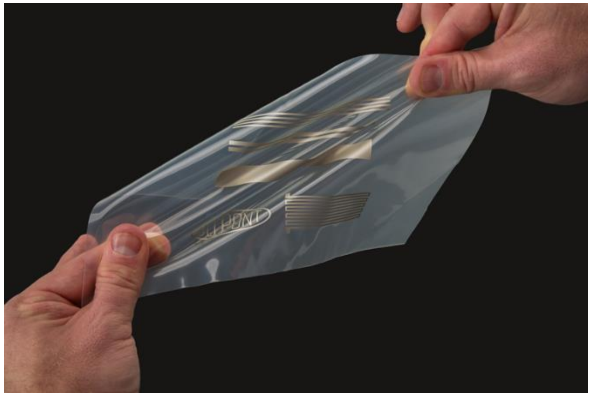


Requirement of compliant electrodes: 1) Inherently soft 2) ↑ conductivity

Stereotypes of electrodes



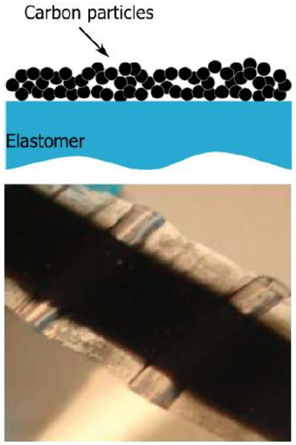
1) A conductive materical is generally **non-stretchable**.



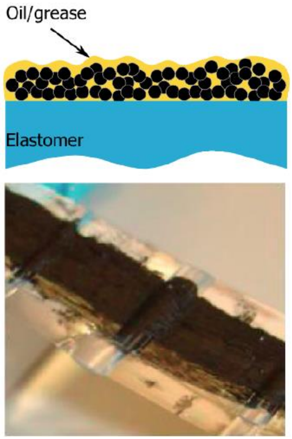
2) A stretchable materical is usually **non-conductive**.

Our goal: soft-conductive polymer

Conventional electrodes for DEs



1) **Losse carbon black**
   - Samuel Rosset (EPFL)
   - Helmut Schlaak (University of Darmstadt)

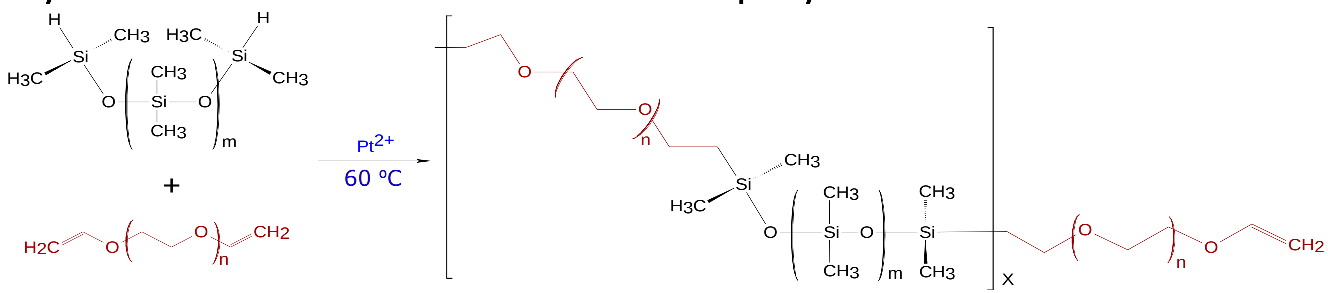


2) **Carbon grease**
   - Samuel Rosset (EPFL)

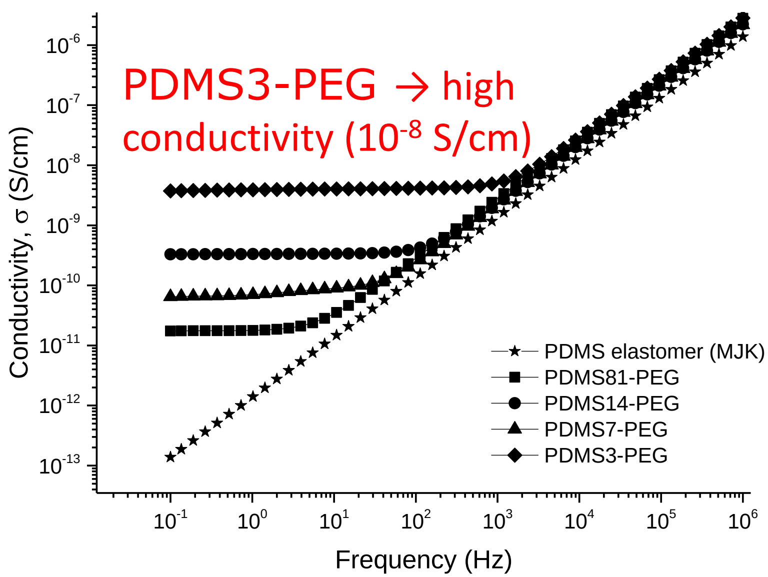
Alternative electrodes:
1) Ionic conductor (hydrogel)
2) Silver nanowires
3) Conductive rubber

PDMS3-PEG copolymer

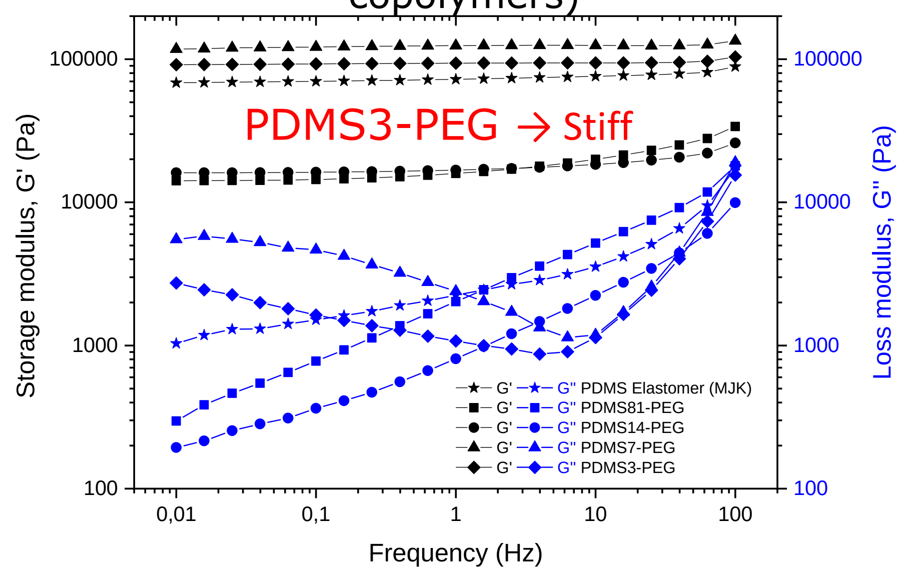
1. Hydrosilylation reaction of PDMS-PEG copolymer:



2. Conductivity (PDMS-PEG copolymers)[1]



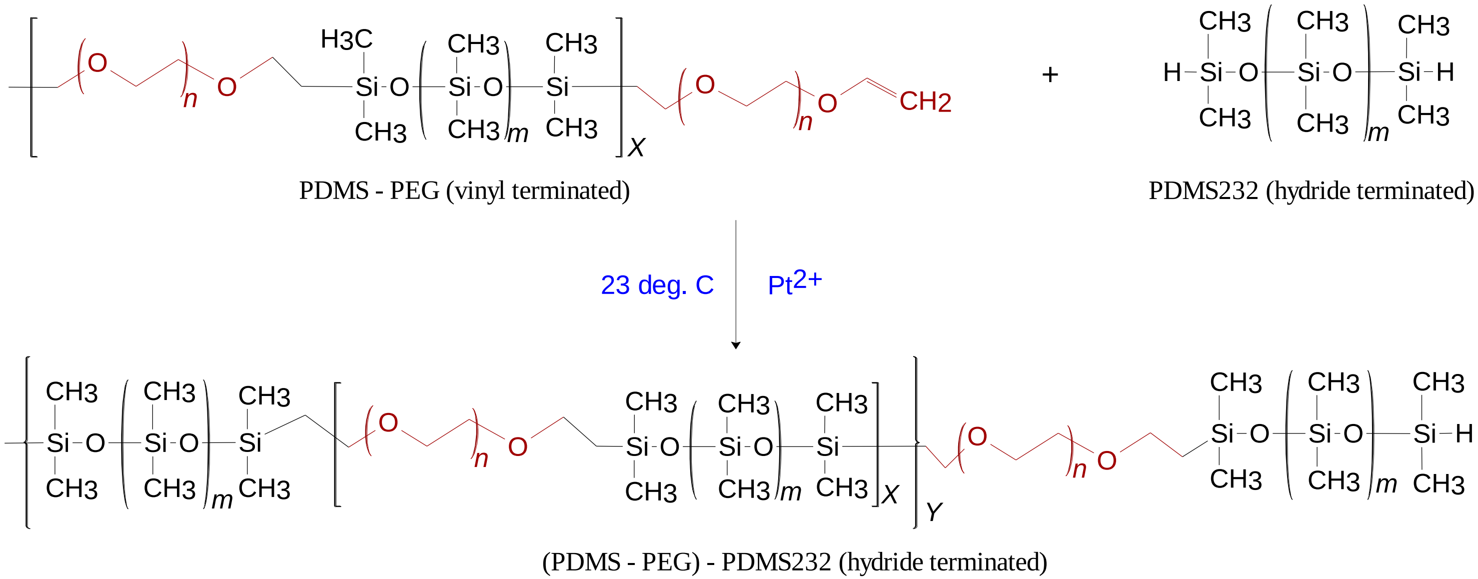
3. Linear viscoelasticity-LVE (PDMS-PEG copolymers)[1]



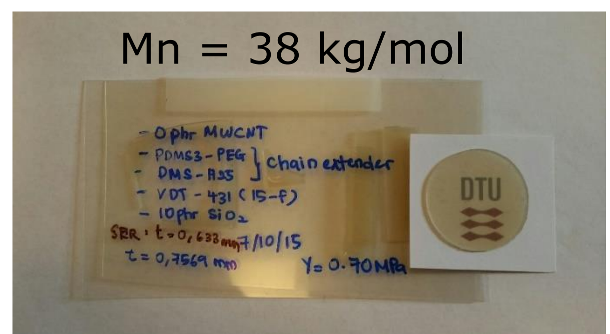
[1] A Razak AH, Szabo P, Skov AL (2015) Enhancement of dielectric permittivity by incorporating PDMS-PEG multiblock copolymers in silicone elastomers. RSC Adv 5:53054–53062

Chain-extended PDMS3-PEG copolymer

1. To obtain a soft-conductive polymer → Chain extended PDMS-PEG copolymer



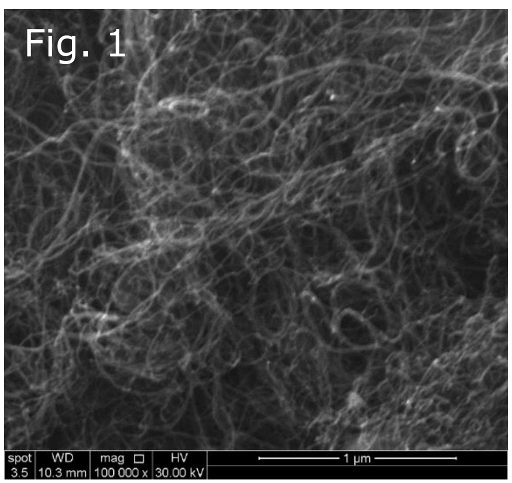
2. Crosslinked copolymer:
   Chain-extended PDMS-PEG copolymer + 15-functional vinyl crosslinker + 30 ppm Pt catalyst



Multi-walled carbon nanotubes (MWCNTs)

1. ↓ conductivity (PDMS3-PEG) → add conductive nanofillers (MWCNTs)

2. Obstacle → MWCNTs entangle

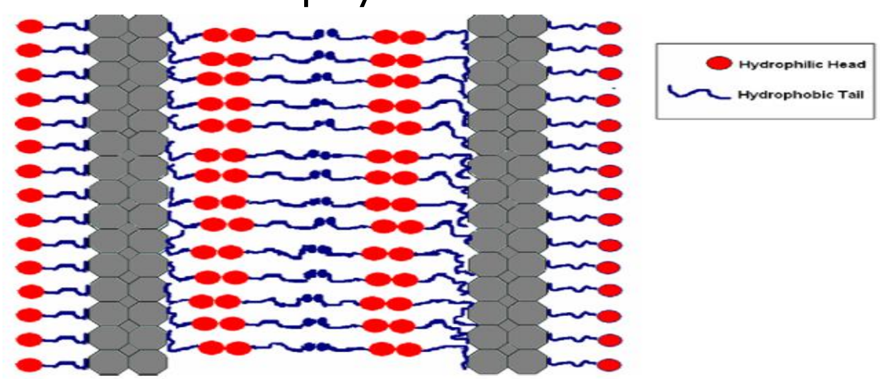


SEM image of pure MWCNTs showing entanglements.

3. Dispersion methods:

Chemical	Mechanical
Oxidation process by acid e.g. HNO_3 & solution of H_2O_2/NH_4OH	1) Probe sonicator 2) Ball milling
<u>Drawback</u>: intrinsic properties of MWCNTs are destroyed due to structural defects	<u>Drawback</u>: rupture MWCNTs into smaller lengths

4. Non-covalent physical treatment



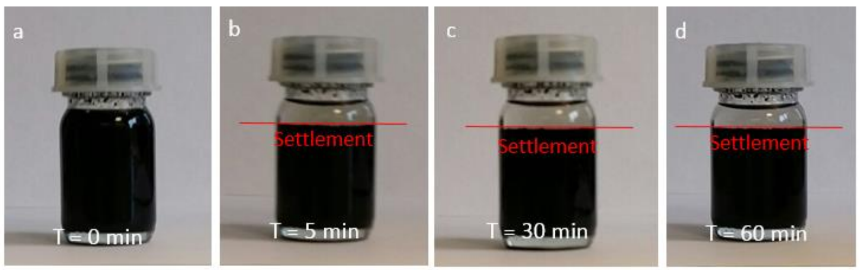
Mechanism of flocculation of CNTs via surfactant molecules.[1]

[1] Rastogi R, Kaushal R, Tripathi SK, Sharma AL, Kaur I, Bharadwaj LM (2008) Comparative study of carbon nanotube dispersion using surfactants. J Colloid Interface Sci 328:421–428

Multi-walled carbon nanotubes (MWCNTs)

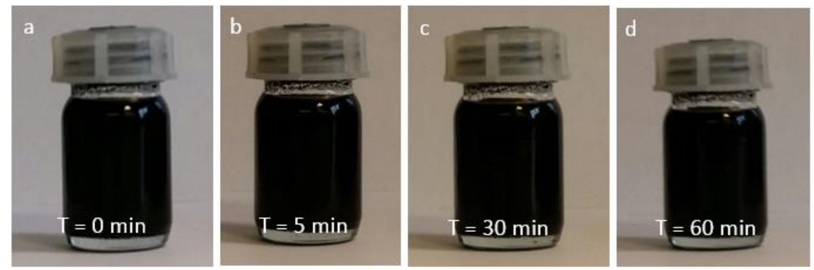
- Dispersion of MWCNTs → Rastogi et al.[1], Geng et al.[2] and Goswami et al.[3]

1.



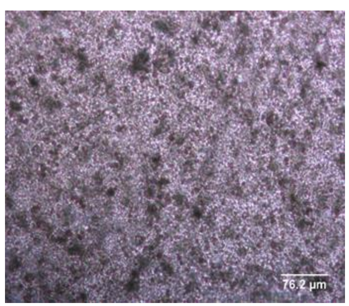
Stability versus time for a reference method (MWCNT/NMP/Triton X-100) dispersed by a mechanical shaker at 23 ° C: a) Immediately b) 5 min c) 30 min d) 60 min.

2.



Stability versus time for MWCNT/NMP/Triton X-100 dispersed by water-bath ultrasonication at 23 ° C for 6 hours: a) Immediately b) 5 min c) 30 min d) 60 min.

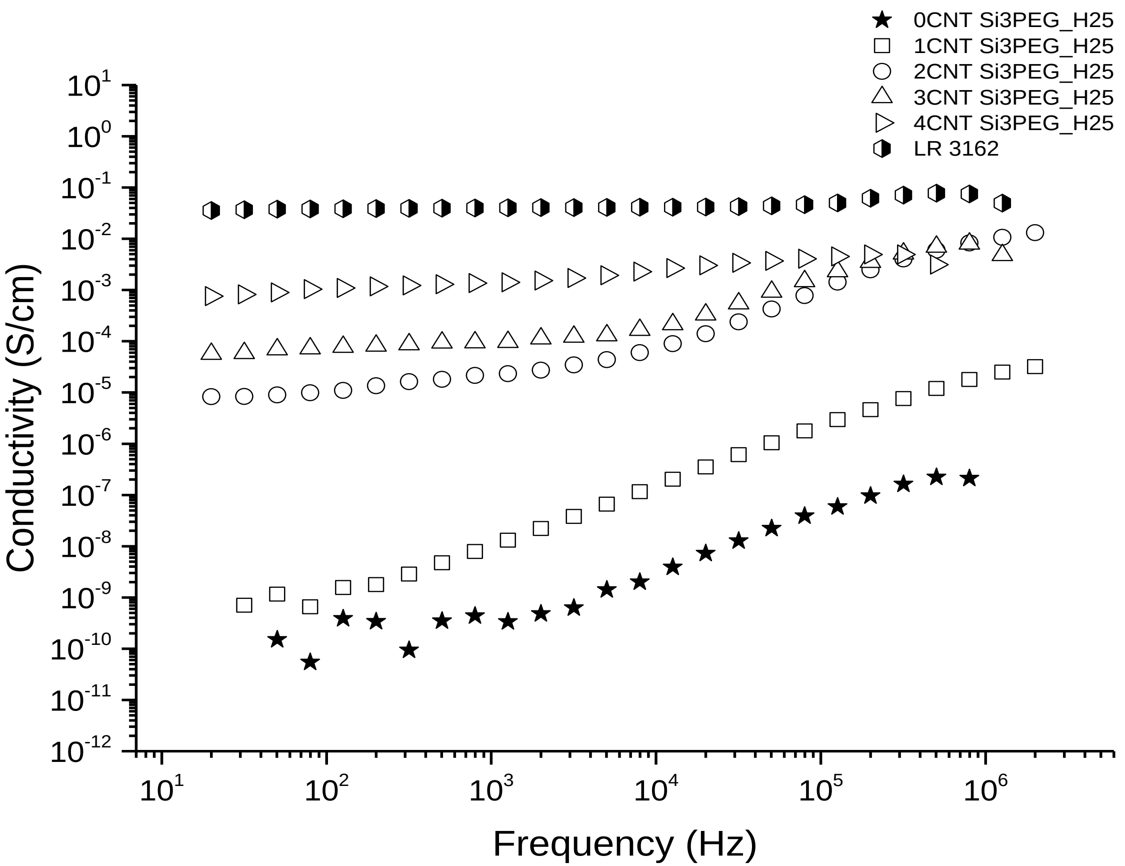
3.



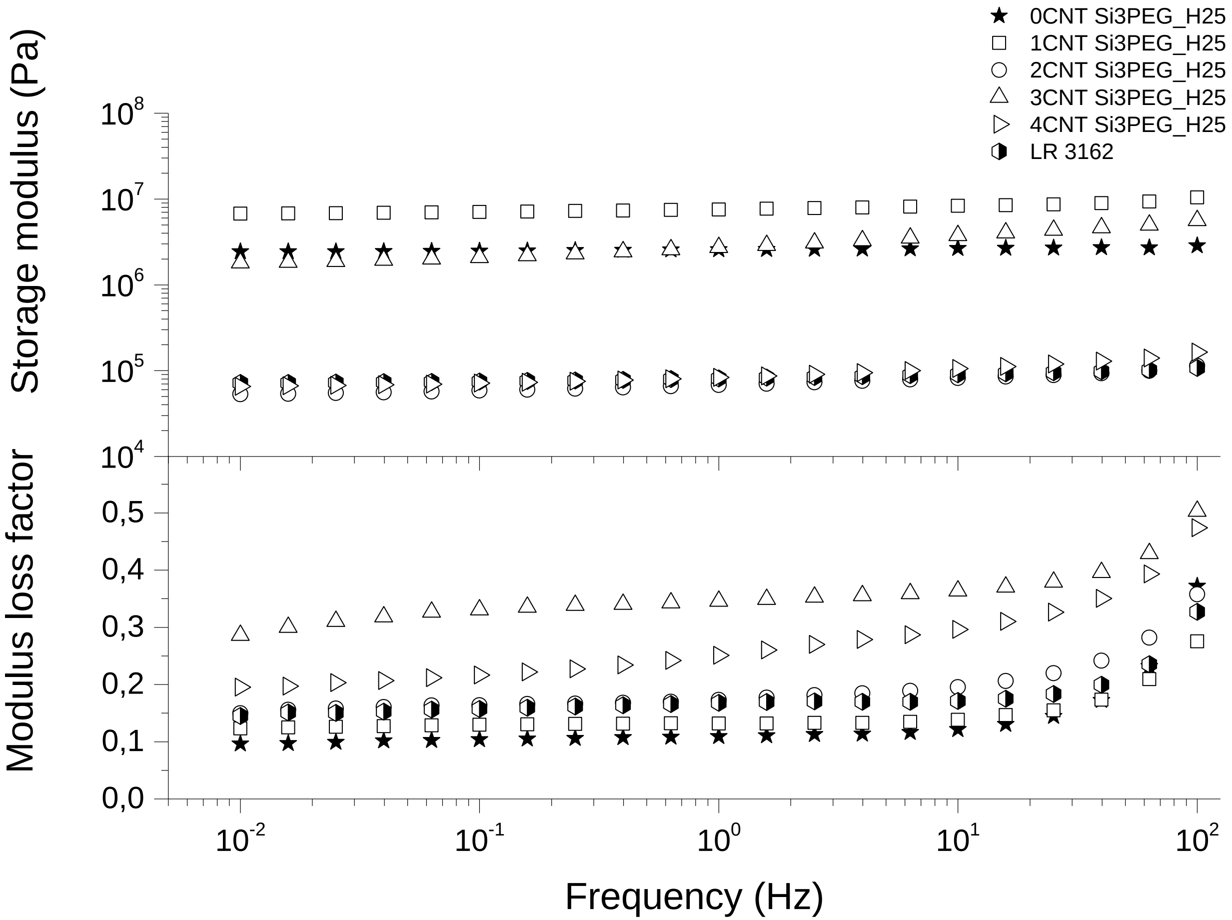
Optical microscope image of this film containing MWCNTs (0.07 phr) in PDMS-PEG matrix.

[1] Rastogi R, Kaushal R, Tripathi SK, Sharma AL, Kaur I, Bharadwaj LM (2008) Comparative study of carbon nanotube dispersion using surfactants. J Colloid Interface Sci 328:421–428
[2] Geng Y, Liu MY, Li J, Shi XM, Kim JK (2008) Effects of surfactant treatment on mechanical and electrical properties of CNT/epoxy nanocomposites. Compos Part A Appl Sci Manuf 39:1876–1883
[3] Goswami K, Daugaard AE, Skov AL (2015) Dielectric properties of ultraviolet cured poly(dimethyl siloxane) sub-percolative composites containing percolative amounts of multi-walled carbon nanotubes. RSC Adv 5:12792–12799

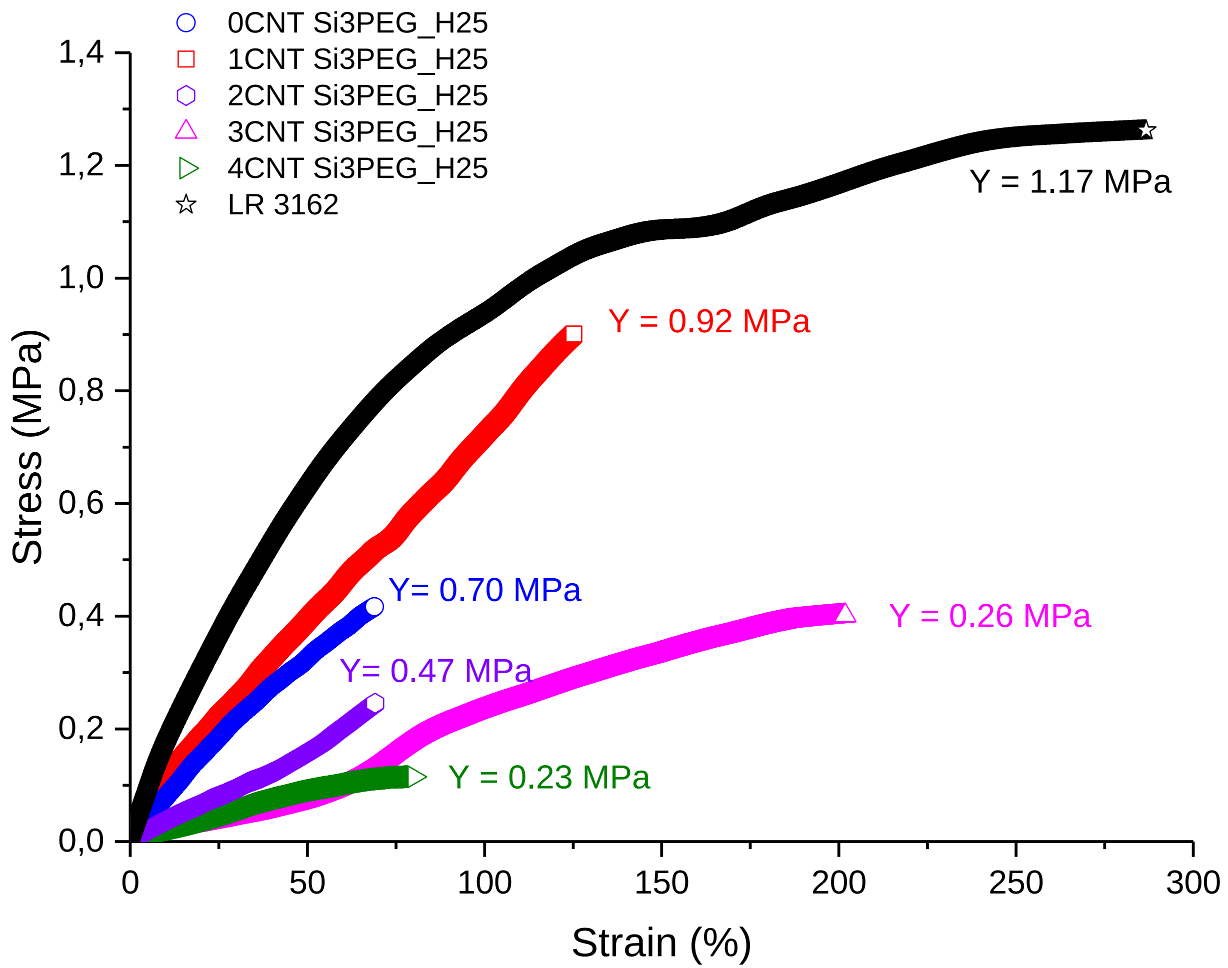
Conductivity & permittivity



Modulus


0CNT Si3PEG_H25
1CNT Si3PEG_H25
2CNT Si3PEG_H25
3CNT Si3PEG_H25
4CNT Si3PEG_H25
LR 3162
Storage modulus (Pa)
10^8
10^7
10^6
10^5
10^4
Modulus loss factor
0,5
0,4
0,3
0,2
0,1
0,0
10^{-2}
10^{-1}
10^0
10^1
10^2
Frequency (Hz)

Stress-strain plots



Conclusion

- The cross-linked conductive PDMS-PEG copolymers were successfully prepared with addition of different MWCNT concentrations.
- The conductivity of the chain-extended elastomers increases nearly to 10^{-3} S/cm;
  - < LR3162 = 10^{-1} S/cm
- The mechanical properties of chain-extended PDMS-PEG copolymers with MWCNTs (< 3 phr) indicate soft networks with low modulus losses.
- Future work:
  - The conductivity can be improved by adding silver nanoparticles in the system if properly designed.
  - Measure the conductivity of samples in “stretch” mode.

DTU

Acknowledgement

KEMENTERIAN PENGAJIAN TINGGI · MALAYSIA · MINISTRY OF HIGHER EDUCATION

UTHM
Universiti Tun Hussein Onn Malaysia

Innovation Fund Denmark
RESEARCH, TECHNOLOGY & GROWTH